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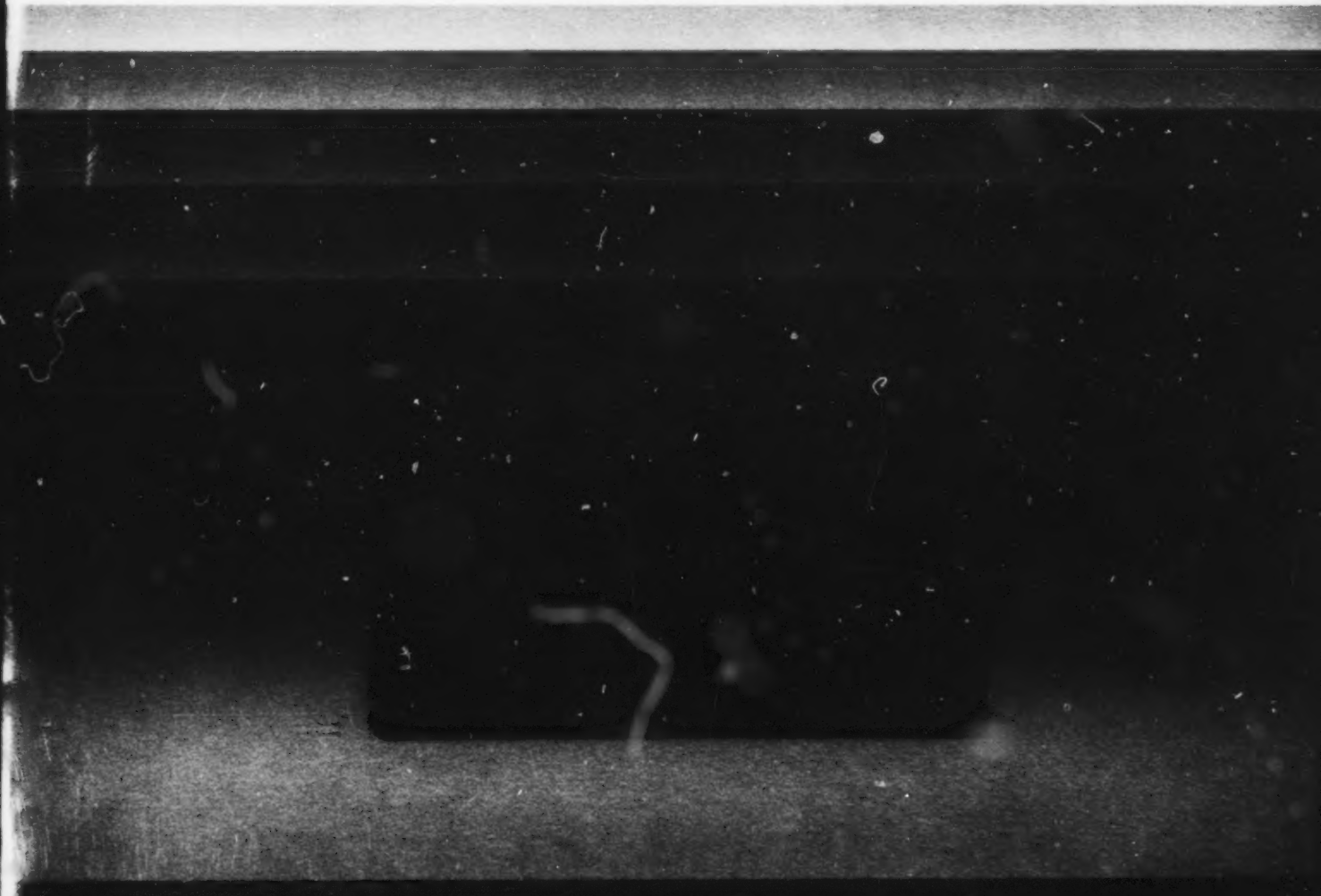

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RECENT WORK ON SNOW AND ICE: 1990 CANADIAN REPORT FOR ICE, NEWS BULLETIN OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

NHRI Contribution No.91036

July, 1991

MANAGEMENT PERSPECTIVE

The establishment of a national or international focus for hydrology at the National Hydrology Research Institute means that staff there accept positions with national and international bodies. Apart from his role as the National Correspondent to the International Commission on Snow and Ice, Simon Ommanney is also the National Correspondent to the International Glaciological Society. One of his roles is to prepare an annual report on snow and ice research in Canada for publication in ICE, the News Bulletin of the International Glaciological Society.

ABSTRACT

This report briefly outlines research undertaken in Canada in 1990 that falls under the broad classification of glaciology according to the International Glaciological Society. It deals with the following aspects of the cryosphere: glaciers and ice sheets; river, lake and sea ice; physics of ice; snow, avalanches and atmospheric ice; ground ice, permafrost and ice as a material. There is an attempt to emphasize the results obtained. For field studies, the summaries are organized in rough geographical sequence moving anti-clockwise from the arctic islands through the territories, British Columbia, the Prairies, Ontario and Quebec to the Atlantic Provinces.

Complete details on the summaries in this report are contained in the following four Contribution Series reports: Canadian Snow and Atmospheric Ice References (1990-1991) and Recent Work (CS-91032); Canadian Glacier References (1990-1991) and Recent Work (CS-91033); Canadian Lake, River and Sea Ice References (1990-1991) and Recent Work (CS-91034); and Canadian Frozen Ground and Ice Properties References (1990-1991) and Recent Work (CS-91035). These are available on request from the National Hydrology Research Institute in Saskatoon.

RECENT WORK - CANADA

GENERAL

CRYSYS-A CRYOSPHERIC SYSTEM TO MONITOR GLOBAL CHANGE IN CANADA

R. Simard, J. Cihlar, T. Fisher, R. Leconte, M. Manore, M.-C. Mouchot (CCRS) et al.

An information system for understanding and monitoring global change in Canada using cryosphere variables such as sea ice, snow, permafrost, glaciers, ice caps, and lake and river ice is being developed. The project is not yet fully implemented, but has been endorsed by NASA.

M.M. Brugman, T. Prowse, A. Wankiewicz and S. Ommanney (NHRI)

Brugman is a principal investigator and team leader for the Glaciers and Ice Caps unit of CRYSYS. Other NHRI team members include Prowse for Lake and River Ice, Ommanney for Information, and Wankiewicz for Snow. The first field experiment took place in the spring of 1991 in conjunction with a NASA overflight. The first deliverable will be the glacier inventory of Yukon Territory to be completed by Ommanney in 1992.

NORTHERN HYDROLOGICAL RESEARCH

T.D. Prowse and C.S.L. Ommanney (NHRI)

Following a standard format, reviews were written by various Canadian northern specialists on: general northern hydrology (T.D. Prowse); snow hydrology (P. Marsh); permafrost hydrology (M.-K. Woo); groundwater hydrology (R.O. van Everdingen); hydrology of floating ice (R. Gerard); glacier hydrology (G.J. Young); water quality (D.J. Gregor); regional energy balances (W.R. Rouse); regional hydrology (J.H. Wedel); and water management (B. Gibson); and published by NHRI as Science Report No.1. The Proceedings of a Symposium on the same topic, held in Saskatoon, 10-12 July 1990, will be published in 1991.

ADVANCEMENT OF NORTHERN SCHOLARSHIP

ACUNS, 1915-130 Albert Str., Ottawa, Ont, K1P 5G4

The Association of Canadian Universities for Northern Studies advances northern scholarship through education and research, including research and teaching about ice and snow and the sponsoring of conferences.

WORKSHOP ON THE MACKENZIE DELTA

P. Marsh and C.S.L. Ommanney (NHRI)

A Workshop on the Mackenzie Delta, environmental interactions and implications of development, was held from October 17-18, 1989, at the National Hydrology Research Centre, Saskatoon, Saskatchewan. The proceedings will be published in mid-1991.

PROJECT WILD SNOW AND ICE

C.S.L. Ommanney (NHRI)

The Canadian Wildlife Federation is developing environmental teaching components for Grades 1-13 based on snow and ice as part of a supplementary curriculum program known as Project WILD. NHRI is collaborating with them by providing background information on possible themes and units.

GLACIERS

GLACIER MASS BALANCE WORKSHOP, SEATTLE

M.M. Brugman and C.S.L. Ommanney (NHRI) with D.S. Munro (GEOG/UTE) and U.S.G.S.

A new era in U.S./Canadian collaboration on glacier research was ushered in with the creation of a North American Committee on Climate and Glaciers and the subsequent successful organization of a workshop on glacier mass-balance methodology in Seattle, sponsored by the NRC Subcommittee on Glaciers.

M. Brugman and G. Østrem (Norway) are collaborating on a new edition of the glacier mass balance manual that has served as an international standard for the last 25 years.

FRACTURE MECHANISMS OF ROCK AND MINERAL FRAGMENTS TRANSPORTED BY GLACIERS

H.H. Schloessin (GPHYS/WEST) with W.C. Mahaney (YORKA)

Rock and minerals on and within glaciers are relatively well-preserved and can suffer fracture from frost splitting and mutual contact. However, those within an ice body form misfitting inhomogeneous inclusions and elastic inhomogeneities in an applied stress field which can generate high stress concentrations leading to fracture. The feasibility and efficiency of this type of fracture in ice are supported by theory and the results of some simple laboratory tests.

LARGE GLACIOFLUVIAL SYSTEMS

T.A. Brennand (GEOG/ALTA)

Some glaciofluvial systems of eskers in southern Ontario and Quebec appear to be composed of a number of large-scale building blocks or bedforms, which together suggest powerful, pulsating flows, at the time of formation.

ICE-MARGIN POSITIONS DURING THE WISCONSINAN

J.-M.M. Dubois et M. Parent (CARTEL)

A Late-Glacial remnant ice cap has been identified in the Eastern Townships. There was another on Anticosti island that marked the margin of the Laurentide Ice Sheet throughout the Wisconsinan. Only the southern portion of the Magdalen Islands was covered in ice.

GLACIERS - ARCTIC

ICE CORE ANALYSIS AND CLIMATE CHANGE

R.M. Koerner, B.T. Alt, J.C. Bourgeois, R. Dubey, D.A. Fisher and M. Parnandi (TSDGSC)

Based on results obtained to date, the present climate shows no trend over the past 30 years. The 100-year trend is for warming which is not unique in terms of the past 10,000 years.

The mass balance of four ice caps was again measured in the Queen Elizabeth Islands. Two of the ice caps have been measured regularly for 30 years; separate records exist for ice melt and snow accumulation.

Shallow ice cores from northern Ellesmere have been studied for anion and cation concentrations from 1880 to 1988. Results, particularly since about 1955, confirm earlier studies of increasing pollution concentrations in recent snows.

Ice-flow properties, deduced from continuing borehole closure measurements, are being modelled in

conjunction with detailed ice-vector measurements made by E. Waddington (Univ. Washington). For the second complete year, six hourly averages of air temperature, relative humidity, snow depth and firn temperature (2.5, 5.0, 7.5 and 10-m depth) were recorded on the Agassiz Ice Cap. The data-logger was restarted and another set up at the top of the ice cap. A new electro-mechanical ice drill, based on the Danish shallow drill, will be field tested in the spring of 1991.

Snow samples from Agassiz Ice Cap show the relationship between seasonal and annual pollen concentrations and synoptic climate. 50-L pre-Holocene ice samples from one of the boreholes were analyzed, and three separate one-tonne snow samples, collected 1 km from the Ice Island camp of the Polar Continental Shelf Project, and from the Agassiz and Devon Ice Caps, were melted and filtered. The filters will be analyzed for micrometeorites at "Le Centre des Faibles Radioactivités, Gif-sur-Yvette, France.

Vapour transport was modelled to simulate $\delta^{18}O$ and δD concentrations. The Reeh 3-D ice-sheet model was modified and used for time slice representations of the Laurentide Ice Sheet between 10,000 and 6,000 years ago. Mean synoptic situations have been related to accumulation and ablation conditions on Canadian ice caps using a Soviet model as part of a co-operative study between AES, the GSC and the Arctic and Antarctic Institute in Leningrad, U.S.S.R.

Trace Organic Compounds in Snow and Ice

D.J. Gregor (NWRI)

Twenty stations throughout the N.W.T. were sampled in 1990 for total annual deposition of organochlorines including pesticides, PCBs and PAHs. A snow pit was sampled on the Agassiz Ice Cap, Ellesmere Island for annual contaminant deposition and residues. The 10-m pit will provide a record from 1960 to the present.

Axel Heiberg Island, N.W.T.

W.P. Adams and M.A. Ecclestone (GEOG/TRENT)

Two years in the 30-year mass balance record of White Glacier show net losses an order of magnitude larger than mean net loss. Similarly, for the Baby Glacier, occasional high net-loss seasons offset years of net accumulation. Such years, through their impact on glacier drainage systems, have great impact on the regional hydrology.

G.J. Young and P.J. Glenday (CRRC/WLU)

White Glacier will be resurveyed and mapped to assess the glacio-hydrological response to climatic fluctuations since 1960.

Y. Moisan (CARTEL)

Recent changes in the snout and proglacial zone of the White and Thompson Glacier complex, based on surveys of the distal perimeter in 1989, were analyzed.

Ice-Cap Monitoring

J.R. Weber (GDGSC) and R.M. Koerner (TSDGSC)

As part of global-change studies to measure absolute elevation changes of arctic ice caps, the first measurements on the Devon and Agassiz Ice Cap summits were made using a micro-gravimetric method controlled with GPS positioning. The Barnes Ice Cap survey is scheduled for the end of July 1991.

Barnes Ice Cap, Baffin Island

J.D. Jacobs (GEOG/MUN) & R. Heron (GEOG/WIND)

Preliminary findings from the northwest margin of the Barnes Ice Cap show a 620-m retreat of Lewis Glacier from the snout position in 1961. Northwards the retreat of the ice-cap margin was less than 200 m in the same period, while to the south, at Triangle Glacier, more than 1 km of retreat has occurred.

GLACIERS - YUKON

Mt. Logan (5951 m) Ice Core Analysis

G. Holdsworth, S. Fogarasi and B. McCarthy (NHRI)

Snow accumulation rates from A.D. 1700-1860 are significantly-lower than from 1860 to 1987. There is a teleconnection between the Mt. Logan net snow-accumulation time-series and some instrumental precipitation time-series elsewhere in the Northern Hemisphere. The main atmospheric pollution of high-altitude snow is by volcanic-eruption gas plumes and possibly forest fires; apart from atmospheric nuclear-weapons testing, there is no evidence of other anthropogenic acid pollution.

The stable isotopes of water show a distinctive altitudinal distribution. Several profiles indicate an iso-δ step separating a lower region of altitude-dependent isotopic fractionation (1750-3350 m), from another sequence above about 5300 m. The gross features can be explained by the structure of the lower- and mid-troposphere and are compatible with the concept of secondary-source moisture arriving via the upper troposphere.

Eclipse Ice Core Site, Y.T.

G. Holdsworth and A. Dalton (NHRI)

An automatic weather station was established at Eclipse to help interpret some aspects of the ice-core record. Temperature and wind data were collected for the winter 1989/90. The station will be removed in 1991.

Canadian-Rufli-Rand Ice Core Drill

G. Holdsworth, M.N. Demuth and A. Dalton (NHRI)

The remaining electrical, hydraulic and mechanical assembly work for the new Canadian-Rufli-Rand Ice Core Drill was completed. The drill was field tested in the Saint Elias Mountains and at Eclipse station. An engineering and operational/logistics manual for the new drill system is now being prepared.

Cause and Mechanics of Glacier Surging

G.K.C. Clarke, E.W. Blake, D.B. Stone, T. Murray, U.H. Fischer, B.S. Waddington and J.P. Schmok (GPHYS/UBC)

Trapridge Glacier, Yukon Territory, lies on an unlithified bed. Sediment deformation contributes substantially to the total flow and may lead to complex interactions with the subglacial water system that might be the cause of flow instability.

Sedimentation in Glacier Ice-Dammed Lakes

P.G. Johnson and J.N. Kasper (GEOG/OTT)

The variability in input of water and sediment to a lake in the Kaskawulsh Glacier system produces annual, daily and short time frame changes in the sedimentary record. Deltas formed during the filling of the lake have a retrogressive stepped form and are entirely reworked either during the drainage of the lake or during the subsequent filling. The fossil record of the lake demonstrates a semi-permanent period which has evolved into annual draining with downwasting of the damming glacier since the Little Ice Age. Hence there are problems using the sedimentary record from alpine glaciers to reconstruct a glacier hydrological record.

Hydrological System of Alpine Glaciers

P.G. Johnson and G. Kruszynski (GEOG/OTT)

From discharge, suspended sediment load, climatic conditions, and the geology and topography of the basin, a linked-cavity and conduit-drainage system model has been proposed. It evolves spatially and temporally in response to precipitation and melt. Seasons dominated by: snow and ice melt produce a temporal trend in the up-glacier progression of cavity-to-conduit connection, release of water from cavities producing pulses in the discharge; early rainstorms force the opening of conduits and have less-progressive release of cavity-stored water. Where the suspended-sediment source is primarily subglacial, variations in concentrations are produced by migration of conduits.

Variability in Glacier Discharge and Suspended Sediment Regimes

P.G. Johnson and G. Kruszynski (GEOG/OTT)

Pulses in discharge and suspended-sediment concentration occur frequently over short time-scales. They are not necessarily correlated, so that there are both dependent and independent events, and can be one order-of-magnitude greater than the background flow. Various discharge-pulse patterns can be recognised on the hydrograph. The suspended-sediment source depends on the characteristics of each glacier and glacier basin, varying from mobilisation at the terminus to subglacial sources.

GLACIERS - BRITISH COLUMBIA

"Mawer" Glacier, B.C.

J.P. Schmok and M. Maxwell (SNOW)

An isopach map from radar depth measurements of the lower five kilometres of "Mawer" Glacier was produced to guide subsequent rotary drilling for minerals.

Tats Glacier, Alsek Ranges, B.C.

J.P. Schmok and M. Maxwell (SNOW)

Glacier mass-balance, radar depth, subglacial water-pressure, subglacial-water transit times, surface-flow and strain characteristics were measured in the summer of 1990 to provide baseline data required for the Windy Craggy environmental impact assessment (EIA).

Geddes Resources Consultants including K. Ricker (RICK/ACC)

Study of the moraines down-valley show that, during the Kluane Glaciation, the glacier forelands were levelled by a southeastward moving ice sheet. The smallest and closest moraine to the snout of Tats Glacier was laid down ca. 1950, indicating an annual retreat of about 7.0 $m \cdot a^{-1}$ to 1987. The glacier has a snout covered by a thick debris mantle which tends to retard ablation, but it does not appear to be a surger despite its looped medial moraines. The glacier is the main access route to the Windy Craggy Mine.

M.M. Brugman (NHRI)

Phase I of the Geddes EIA statement on the proposed Windy Craggy Mine was reviewed. The glaciological problems identified were incorporated into the next phase requirements identified by EC in Vancouver.

High Runoff Fiords, North Coast, B.C.

K. Ricker (RICK/ACC) and J.W. McDonald (Seakem Oceanography Ltd.)

Fiord with high glacier-melt discharge are unsuitable for net pen salmonid aquaculture because of diluted, turbid surface waters. Undesirable fiords from 53° to 56°N have been identified. They include the Portland and Observatory Inlet areas with large mountain ice sheets (100s of km^2 in extent) as well as the Douglas and Gardner waterways with "hundreds" of small glaciers (only a few km^2 in extent).

Iskut River Basin, B.C.

O. Mokievsky-Zubok and A. Chichagov (GCS)

The three glaciers studied, Andrei, Yuri and Alexander, showed a negative 1990 mass balance of - 0.42, - 1.07 and - 1.07 m H_2O respectively.

Homathko River Basin, B.C.

O. Mokievsky-Zubok and A. Chichagov (GCS)

The two glaciers studied, Tiedemann and Bench, showed a negative 1990 mass balance of - 1.56 and - 1.06 m H_2O respectively.

Overlord Glacier, Coast Mountains, B.C.

K. Ricker (RICK/ACC) and W. Tupper (BCIT)

Up to about 1987 Overlord Glacier had been markedly advancing. Two surveys of the snout since then have shown a slight recession of about 1.5 $m \cdot a^{-1}$. Three moraine crests have been assigned the following ages: 1748-1821 A.D., 1875-1884 A.D., and 1911-1923 A.D. Historical photos show a younger moraine developed prior to 1931 A.D. The healthy state of Overlord Glacier is attributed to several factors: large névé-to-outlet-tongue area ratio; névé elevation above the regional snowline of about 2000 m (for ice-covered surfaces); and an overall favourable aspect.

Mountain Hydrology and Glacial Meltwater

M.M. Brugman (NHRI)

A strategy for future NHRI mountain hydrology studies was developed during the fall of 1989 and forms the basis of the program carried out in the summer of 1990 in the Rockies and Coast Mountains. This is the re-activation of a long-term program begun in the early 1960s for the IHD. During 1990, the studies at Peyto, Sentinel, Helm and Place Glaciers were re-established and measurements of the winter, summer and net balances obtained. Two new meteorological stations were installed and tested.

Wedgemount Glacier, Coast Mountains, B.C.

W. Tupper (BCIT) and K. Ricker (RICK/ACC)

Photo-theodolite and field-camera surveys of the lower glacier and snout were carried out from 1988 to 1990, and upper stations were occupied in 1990. Ablation stake measurements were discontinued in 1987. Ice recession continues and the snout is no longer a cliff-fronted feature calving into the lake. In 1990 the equilibrium line was much higher than usual; the surface was extremely rough and dirty at the usual equilibrium line (ca. 2150 m). Surveys of the glacier will be conducted biennially except for the quadrennial year of the WGMS reports.

Coast Mountain Glaciers, B.C.

M.M. Brugman and T. Carter (NHRI)

Following the retirement of O. Mokievsky-Zubok, UBC undertook the mass-balance, geodetic and photogrammetric surveys of Place, Sentinel, and Helm Glaciers for NHRI. For the 1989 balance year all glaciers exhibited a specific mass loss (in m H_2O) as follows: Sentinel -0.90; Place -1.04; Helm -1.67. Subnormal snowpacks contributed more to these negative net balances than above-normal summer

temperatures. Cumulative balance data indicate a mass loss from Place Glacier of 16.88 m H_2O since 1965, and from Helm Glacier of 13.49 m H_2O since 1977. The apparent mass gain of 4.42 m H_2O since 1966 for Sentinel Glacier, which has retreated 570 m, pointed to the urgent need to establish geodetic control on the mass balance. This was done in 1990 and confirmed initial estimates of an imbalance of about 1.2 m.

In 1990, one hut at Sentinel Glacier was completely refurbished. A special investigation of albedo was carried out and tests made on radiation penetration into the snow cover using a spectrophotometer.

Woolsey Glacier

G.J. Young and P.J. Glenday (CRRC/WLU)

Woolsey Glacier is being remapped to assess the glacio-hydrological response to climatic fluctuations since the 1966 IHD survey.

GLACIERS - ROCKY MOUNTAINS

State of Canada's Glaciers

C.S.L. Ommanney (NHRI)

Recent glacier activity and studies in the Rockies during the last century have been documented for the USGS Satellite Image Atlas of Glaciers of the world.

"Small River Glacier" Hydrology

C.C. Smart (GEOG/WEST)

Some 70% of the "Small River Glacier" (B.C.) drains underground through two karst aquifers. Drainage is through low-pressure conduits which enter the aquifers at distinctive sink points at the bed. Catchment boundaries are fuzzy and shift with time and discharge. Much of the basal drainage appears to be adjusted to the conduit system, although some patches are poorly-connected. Runoff from the "discrete" accumulation area is steady and unresponsive. in contrast, the "discrete" ablation area is very flashy with runoff closely tracking solar radiation.

Cline Glacier Ice Mine

M.M. Brugman (NHRI)

Based on available information it was concluded that the effect on mass balance and runoff, of ice mining by the Ice Age Company at Cline Glacier, would be minimal, but claims about the age of the ice could not be supported.

Clear-Sky Net Radiation Field of a Mountain Glacier Environment from Remote Sensing

D.J. Gratton and P.J. Howarth (GEOG/WATER)

LANDSAT-5 thematic mapper yields accurate surface-cover albedo and long-wave emittance values for a mountain glacier basin (Athabasca Glacier). Terrain-reflected and terrain-emitted radiation should not be neglected in many areas of the basin; it represents an important part of the incoming radiation process.

Peyto Glacier, Alberta

M.M. Brugman, G. Holdsworth and T. Carter (NHRI)

The glacier continues to lose mass. A total survey station was used to determine the magnitude of this loss since the IHD map was made. Discharge measurements reveal continuous flow throughout the winter. Wood samples, found near the snout, were prepared for ^{14}C dating and sectioning.

D.S. Munro (GEOG/UTE)

On Peyto Glacier, radiative- and sensible-heat exchange account for most of the energy used to melt snow and ice, the latter accounting for nearly 50% of the energy used to melt snow. Modelling shows that glacier ablation is highly sensitive to radiative exchange terms, particularly the surface albedo.

P.M. Cutler (now at GEOL&GPHYS, Univ. Minnesota) and D.S. Munro (GEOG/UTE)

On the Peyto Glacier tongue visible reflectivities were higher than near-infrared values; over moraine the pattern was reversed. The near-infrared range displayed less spatial variation than the visible. The minimum difference between visible reflectivity at clean and dirty ice was 0.17; near-infrared values differed by only 0.05. Impurity content was more important than surface roughness for spatial variation. The snow showed greater temporal variation. Results suggest a separate treatment of visible and near-infrared reflectivities in glacier-mass balance models. The unresponsive nature of glacier-ice and moraine reflectivity permits confidence in the accurate representation of satellite imagery obtained within a 6-hour period centred on solar noon. For metamorphosed snow the period would be reduced to 4 hours.

P.J. Glenday (CRRC/WLU)

Digital terrain modelling and analysis has been applied to produce a 1989 glacier, slope and aspect map (scale 1:10,000) and to the computation of volumetric change.

Ram River Glacier

G.J. Young and P.J. Glenday (CRRC/WLU)

Ram River Glacier is being remapped to assess the glacio-hydrological response to climatic fluctuations since the 1966 IHD survey.

Little Ice Age Activity, Peter Lougheed and Elk Lakes Provincial Parks, Alberta and B.C.

D.P. McCarthy and D.J. Smith (GEOG/SASK)

Archival and geobotanical data show ice fronts were within 300 m of the Neoglacial maximum positions in A.D. 1916 and are now up to ca. 2.5-km up-valley. Field investigations of 20 forefields found morphological and datable evidence for 14th to 19th century Little Ice Age advances. There is no evidence for recent advances at these sites.

The Rae Glacier Project

D.J. Smith and C. Lawby (GEOG/SASK)

Rae Glacier has retreated 565 m (mean 7.5 $m \cdot a^{-1}$) from a terminal position reached in approximately 1916. Over that interval the total volumetric ice loss has exceeded $1.370 \times 10^7 m^3$ (1916-1958: $8.768 \times 10^6 m^3$; 1958-1990: $4.932 \times 10^6 m^3$).

SNOW - GENERAL

Canadian Snow and Wind Institute

F.H. Theakston (CSWI)

The Winter Cities Association has sponsored a Canadian Snow and Wind Institute. This will be a Canadian centre of expertise in snow and wind control as it pertains to the transportation infrastructure and the safe passage of people and goods. It will co-ordinate activities in this field with respect to research, education, and promotion. Although it is a national organization it will maintain close ties with international councils in other northern regions and countries.

It will establish a data base and offer assistance in training personnel, and organizing meetings, workshops and conferences related to snow and wind problems.

Trafficability of Snow

R.N. Yong, A.M.O. Mohamed and D.M. Xu (GRC)

The energy partition method provides a way of establishing relationships between useful and lost energies due to: a) snow deformation; b) tyre deformation; 3) slip; and 4) total input energy. Field data from a deep snowpack at Fernie, B.C. and predicted data from the proposed model were in good agreement. The model not only determines whether a vehicle can or cannot cross a deep snowpack, but also provides detailed information on the best inflation benefit for a particular payload requirement.

Optical Properties of Falling Snow

D.L. Hutt (DREV)

Commercial forward-scatter meters can be used to estimate visibility in snow with appropriate calibration. Extinction of visible and IR beams by falling snow can be modelled by taking into account multiple scattering effects.

SNOW - ARCTIC CANADA

Isotopic Composition of Arctic Precipitation

F.A. Michel (ES/CARL)

Work is still in progress on determining the isotopic composition (^{18}O, ^{2}H, ^{3}H) of precipitation from AES stations across the Arctic.

Hydroclimatology and Sedimentology of a High Arctic Mountainous Watershed

D.R. Hardy and R.S. Bradley (GEOG/Massachusetts)

Studies are being carried out in northern Ellesmere Island to: quantify winter snow accumulation within a drainage basin and characterize spatial variability of the snow cover; characterize meteorological parameters controlling meltwater production and streamflow; and to characterize the isotopic composition of streamwater inputs (snowmelt, glacier melt, permafrost active-layer melt), and delineate the relative contribution of each.

Hydrology of a Perennial Snowbank, Melville Island, N.W.T.

A.G. Lewkowicz and K.L. Young (GEOG/UTE)

The major water source was snowbank melt and the major sink surface runoff; both exceeded 500 mm making the water flux through the basin more than double that of typical basins in the central Archipelago. The discharge record was characteristically proglacial rather than nival. Energy fluxes at the snow surface were measured from three towers. During the melt season, net radiation accounted for 85% of the energy absorbed, sensible heat 15% and latent heat was a net loss of 2%.

In spring, the snowbank is up to 10-m thick. Tritium concentrations show the basal 2 m of ice pre-dates 1957. The hypothesized climate warming is unlikely to eliminate the perennial snow unless accompanied by substantially less snow drifting at the site.

Residual Snowcover in the Canadian Arctic and Alpine Environments in Summer

B. Lauriol, C. Duguay and D. Lagarec (GEOG/OTT)

Research is underway to: evaluate the regional maximum snow depth in winter in the Kluane Range, Yukon and the Northwest Territories; determine the snow disappearance patterns and fractionation process in northern Canada; assess potential impacts on climatic change; and to derive the reflectance and albedo of snow in alpine environments using remotely-sensed data for improving estimates of the radiation budget.

Runoff in High-Latitude Permafrost Basins

P. Marsh and J. Pomeroy (NHRI)

Results demonstrate the importance of meltwater infiltration into the frozen active layer, and outline the processes controlling active-layer soil moisture - a dominant factor controlling infiltration and therefore snowmelt runoff.

Mesoscale Climatology of Baffin Island

J.D. Jacobs (GEOG/MUN)

Field data and optimal interpolation techniques have improved mapping of summer climatic anomalies in the large lakes region of interior Baffin Island. Automatic station data on winter precipitation improved mapping into the interior of snowfall from winter storm events.

SNOW - WESTERN CANADA

Simulation of a Prairie Snowpack

C. Fisher and R.F. Hopkinson (AESR)

The assumption of one-in-ten for snowfall conversion to water equivalent, in general, overestimates the situation in the southern Prairies. Melt coefficients were varied in an interactive program, the Regina - Saskatchewan Model, where it was demonstrated that no single coefficient was valid throughout the snow season.

Prairie Snow Cover Determination

B.E. Goodison and A.E. Walker (CCC/AES)

Algorithms have been developed and tested for determining snow water-equivalent (SWE) from passive-microwave satellite data for the open-prairie region. One uses a vertically-polarized brightness-temperature gradient has been used for three winter seasons (1988/89 to 1990/91) to produce near real-time SWE maps from SSM/I data for dry-snow conditions. Government water-resource agencies have provided important feedback with respect to validation of the SWE information derived. Over forested areas the "open prairie" SWE algorithm has generally produced values significantly lower than ground measurements.

Storage Capacities of Over-Wintering Crop Residues

H. Steppuhn (SCRS/AC)

Empirical models can determine total storage capacities of over-wintering crop residues, but relating them to snowfall and environmental conditions is difficult.

Snow Transport

J.W. Pomeroy, W.N. Nicholaichuk (NHRI) with D.M. Gray, T. Brown (ENG/SASK) and T.D. Davies (School of Environmental Sciences, Univ. East Anglia)

Wind transport of snow profoundly affects the hydrology of wind-swept cold regions. Over a representative 1-km field in the southern Prairies, typically 42% of snowfall is sublimated annually during wind transport, and 35% is relocated, providing a net snowcover loss of 77% before spring melt. Of the annual snow transport, about 30% is by saltation; the rest travels in turbulent suspension to several metres above the

surface. However, near Resolute Bay, N.W.T., winds maintain a much higher proportion of snow in saltation.

Acidic ion concentrations in blowing snow show a three-fold increase from surface snow in contaminant levels, due largely to sublimation of ice from blowing snow crystals. Hence a two-fold increase in contaminant concentrations in drifted-snow vs. non-drifted snow.

Snow interception in conifer canopies is often controlled by the flexure of the branch. Measurements suggest an explanation for unloading of intercepted snow when warming occurs after a snow-storm. Further measurements are quantifying the flux of snow particles, heat, water vapour, radiation and momentum to conifer branches during and after snowfalls in order to model the snow interception losses of forests.

SNOW - CENTRAL CANADA

Hydrochemical Fluxes during Snowmelt

J.M. Buttle, K. Sami and D. Steele (GEOG/TRENT)

Ground-water contributions to streamflow during snowmelt were attributed to expansion of a ground-water mound under a central wetland and its extension down the stream channel, rather than to a ground-water ridging mechanism operating under adjacent hillslopes. Ground-water recharge through the unsaturated zone is via translatory flow, although bypassing flow was evident in near-surface soils during the initial snowmelt period. Up to 19% of premelt soil water may be immobile. Unsaturated soil hydraulic conductivities estimated using ^2H as a tracer during snowmelt ranged from 1.1×10^{-7} to 6.8×10^{-4} $m \cdot s^{-1}$.

Snowmelt Runoff in Suburban Catchments

J.M. Buttle and A. Vonk (GEOG/TRENT)

Suburban catchments experience higher snowmelt rates than open fields and forests, and respond more rapidly to snowmelt and rain-on-snow events than rural basins do. Progressive suburban development has led to a 6-fold increase in the spring quickflow response ratio and an increase in the number of snowmelt events that generate quickflow. Chloride export patterns during snowmelt and rain-on-snow differ as a result of changes in contributing areas.

SNOW - EASTERN CANADA

Snow-Atmosphere Interaction

H.G. Jones (INRS)

Experiments on the dynamics of chemical species in cold (< -5°C) snowpacks at Lac Laflamme and Schefferville (Quebec) have shown that NO_3 concentrations diminish in snow during certain periods. These experiments were repeated on the Agassiz Ice Cap in 1990 and 1991.

Spring Snowmelt at Lac Laflamme

J. Stein, C. Maulé, M. Prévost, R. Barry and A.P. Plamondon (FOR/LAVAL)

Snowmelt surface runoff is more important than previously thought. There is also a clear indication that the freezing processes at the soil surface is an important processes affecting snowmelt pathways.

Chemistry and Microbiology of Snowmelt

H.G. Jones (INRS)

It has been shown that the interaction of snow melt water with organic particulates (litter fall) in forest snowpacks leads to depletion of NH_4^+ and NO_3 in melt-water discharge. Studies on microbiological populations revealed the importance of snow algae to the dynamics of many ionic species notably NH_4, NO_3 and SO_4.

Late-Winter Snowcover and Climate

C.E. Banfield (GEOG/MUN)

The late-winter snowcover in Grand Lake Basin, Newfoundland, shows considerable inter-annual variability, but with overall maxima in depth and water content during the 1930s and early-1970s, and a minimum in the 1950s. The seasonal climate variables exerting most influence appear to be mean winter temperature and rainfall.

REMOTE SENSING AND METHODS

Workshop on Remote Sensing in Hydrology

A. Wankiewicz, R. Perla and G. Kite (NHRI)

A Workshop on the Application of Remote Sensing in Hydrology was held at NHRC on February 13-14, 1990. It included sessions on Hydrologic Models and Microwave Hydrology. The Proceedings were published as NHRI Symposium No.5.

Sensing of Snow and Ice Properties

M.N. Demuth, M.M. Brugman and T. Carter (NHRI)

A portable, frequency-modulated continuous-wave (FM-CW) radar system (2-4 GHz) is under development. Bandwidth, sweep frequency, FFT windowing and Hibert transformation parameters can be selected by operator. The unit can also be used as a fixed-frequency scatterometer. Preliminary field trials as a fixed-frequency scatterometer have been encouraging.

Passive radar reflectors were deployed in the accumulation zone of Sentinel Glacier, B.C. to determine the viability of replacing mass-balance poles with expendable reflectors. Standard tri-planar corner reflectors were also buried. A sledge mounted FM-CW radar can be guided into position using a remotely-positioned total survey instrument.

Microwave Remote Sensing of Snow

R. Perla (NHRI)

The real permittivity of 200 snow samples, measured with a wide range of density and wetness in a capacitive cell at 1 MHz and at 0°C, fits three empirical functions. In agreement with microwave measurements, the empirical constant (q) was found to be 0.4 for wet snow, but higher at both the dry (0.7) and very wet extremes (0.6). These values are consistent with snow microstructure modelled as a sintered ice skeleton with water inclusions disconnected for low volume proportion of water (v_w) and connected as $v_w \rightarrow 1$.

Satellite Monitoring of Snow & Soil Moisture

A. Wankiewicz (NHRI)

Nimbus-5 ESMR observations from 17 different watersheds were used to estimate spring runoff in the Rocky Mountains and Plains regions. Average snowmelt runoff and microwave brightness are correlated. For Rocky Mountain watersheds (5,000-20,000 km^2) the results are almost as good as conventional snow courses for 1973-1976. Inter-annual variations in snowpack and brightness are localized. For the plains, a good multiple correlation exists

between microwave brightness, spring runoff, and previous October streamflow.

In the Iron Creek (3,500 km²) and Antler River (3,200 km²) basins, a microwave emissivity index was computed as the ratio of monthly mean brightness to surface temperature. This index could be used to monitor monthly basin moisture status.

Models and Remote Sensing

G. Kite (NHRI)

Watershed model performance was improved with the use of daily snowcover data from the NOAA visible and IR bands and with land classification data from LANDSAT but not with NOAA cloud-cover data.

Use of SAR for Snow Hydrology

R. Leconte (CCRS) and D. Mullins (Intera Kenting)

The qualitative and quantitative interpretation of airborne SAR imagery, acquired in spring 1990, and the development of microwave models of snowpacks, that will be tested using airborne data, has started. Initial findings suggest that dry snow is not completely transparent at X- and C-band frequencies, and that the interaction microwave-energy/snowpack/soilis complex and depends on such factors as soil state (frozen, unfrozen), layering and the presence of ice layers in the snowpack.

WMO Solid Precipitation Intercomparison

B.E. Goodison and J.R. Metcalfe (CCC/AES)

An octagonal, vertical, double-fence shield surrounding a Tretyakov precipitation gauge is the reference standard. Canada has established six evaluation stations representing different climatic and physiographic regimes. Wetting losses for the Canadian Nipher Shield Snow Gauge System (National Standard), a non-recording gauge, are significant and initial results suggest they could be slightly higher for old gauges. The addition of the large Nipher-type shield on recording gauges at automatic stations, particularly in windy environments, offers a viable method of minimizing catch errors while providing measurements compatible with Canadian National Standard.

B.E. Goodison, J. Metcalfe and K. Jones (AESR)

Results from the intercomparison show that the Canadian Nipher and large-scale Nipher are very similar as well as Russian double-fenced snow gauge. The U.S. Wyoming catches about 75% and Alter shields only 50-60% of the Canadian gauges.

Spatial Prediction of Snowcover Development

H.B. Granberg (CARTEL) with G.J. Irwin (DRES)

Useful information on snow conditions can be derived from digital-terrain information and standard weather data.

AVALANCHES

Snow Slope Stability Evaluation and Avalanche Hazard Forecasting

C.D. Johnston and J.B. Jamieson (ENG/CAL)

Work continues on refining and evaluating various field tests of snow-slab stability (e.g., rutschblock shear frame) as well as assessment of the spatial variability of the shear strength of active weak layers.

ATMOSPHERIC ICE

Atmospheric Icing of Structures

J.A. Druez (UQAC)

Work continues of ice accretion and shedding rates on electrical conductors as a function of conductor type, ice loads on power lines and icing events duration.

The adhesive, tensile and comparative strength of glaze, rime and spray-ice is being investigated as a function of temperature, wind velocity, liquid-water content, droplet diameters and strain rate.

Ice Accretion on Insulators and Conductors

M. Farzaneh and 10 researchers (UQAC)

For low or medium intensity ice accretion, the amount of ice accreted on a H.V. conductor is much higher under positive and alternative voltages than under a negative voltage. There is no major change in the weight, density or grain texture of hard rime grown on the surface of insulators submitted to dc or ac high voltage. Minimum flashover voltage of an insulator covered with hard rime is about 40% lower than that of a wet insulator.

PERMAFROST AND GROUND ICE

Clarification of Perennial Ground Ice by Thermally-Induced Regelation

E. Perfect, P.H. Groenevelt and R.D. Miller (LRS)

The model predicts net upward migration of mineral particles embedded in ice-rich permafrost under the influence of surficial temperature oscillations. This movement occurs over a relatively narrow time band within each annual cycle. A maximum flux of 10^{-11} $m \cdot s^{-1}$ was calculated at the permafrost table. Fluxes decrease rapidly with the depth. Over geological time, embedded mineral particles will be expelled into the overlying active layer leaving ice as a pure phase in the thermo-active zone. This fits with field observations of the vertical distribution of perennial ground ice.

Movement of Steel Rods through Warm Ice

D.H. Shields and L. Domaschuk (ENG/MAN)

The rods quickly moved to steady-state (secondary-creep) displacement conditions. There was no sign of failure (tertiary creep). There were both instantaneous (elastic) displacement and primary creep on initial application of the load.

Ground Ice Studies in the U.S.S.R.

F.A. Michel (ES/CARL)

The ground ice at the several sites on the Yamal Peninsula, northwest Siberia, U.S.S.R, investigated to date can be classified as wedge ice or segregated ice.

PERMAFROST - BEAUFORT SEA

Onshore/Offshore Transect, Beaufort Shelf

S.R. Dallimore, S. Blasco, D. Gillespie, J.A. Hunter, P.J. Kurfurst, A.S. Judge, F.M. Nixon, B.R. Pelletier, S.E. Pullen, A.E. Taylor and J.-S. Vincent (TSD/GSC)

This program will document permafrost conditions in the upper 100 m of the coastal margin of the Beaufort Shelf and correlate them with onshore areas. It involves route selection, drilling, geophysical surveys, ground thermal-data collection, sample testing and data analyses. Ground-ice studies include salinity, isotopes and chemistry as well as geothermal modelling.

PERMAFROST - TERRITORIES

Nature and Origin of Ground Ice
W.H. Pollard (GEOG/McG)
Regionally (e.g. Herschel Is., Yukon Coast, Fosheim Peninsula) ground-ice characteristics have provided information on paleoclimate conditions associated with ground-ice aggradation as well as recent climate changes post-dating ground ice. These studies are improving knowledge of the distribution and range of contents of ground ice which will be important in the event of global warming.

Development of Ice Wedges
A.G. Lewkowicz (GEOG/UTE)
Data collection and analysis is in progress on relation past and present ice-wedge growth to climatic factors on Fosheim Peninsula, Ellesmere Island.

Hydrological Processes
M.-K. Woo (GEOG/McM)
Satellite images taken during the snowmelt season revealed patches of early melt zones, tens of kilometres across, on the lowlands of Fosheim Peninsula. Temperatures, snow ablation, and frost-table depths within and around one such patch showed it had higher temperatures, earlier snowmelt, and a deeper frost table. Superimposed on the meso-scale climatic and hydrological characteristics are local influences of slope orientation and elevation. Sites established in 1989 continue to define spatial and temporal changes in the thermal and hydrological regimes.

Precipitation is the major moisture source during years with near-normal temperatures while ground-ice melt provides an alternative source during warmer years. This fail-safe moisture supply ensures lusher vegetation than expected of polar deserts.

Characterization of Ground Ice Canada
S.R. Dallimore (TSDGSC)
The development and testing of models of ground-ice characterization within permafrost regions of northern Canada and the Cordillera continues. A report summarizing ground-ice occurrence in the Beaufort Sea Coastlands is in preparation.

Geological and Geotechnical Conditions, Beaufort Sea Coastal Zone
S.R. Dallimore, J.R. Bélanger, A.S. Dyke, A.S. Judge, P.J. Kurfurst, P.A. Egginton, J.-S. Vincent and J.A.M. Hunter (TSDGSC)
Work includes laboratory analysis and modelling to characterize material and ground-ice properties in the Yukon Coastal Plain, the Mackenzie Delta, the Liverpool Bay area and on Richards Island and the Tuktoyaktuk Peninsula.

Permafrost/Climate Relationships
D. Etkin and A. Headley (CCC/AES)
The existing climate data base was examined to determine the extent of any changes in climate parameters of importance to permafrost regimes in the Mackenzie Valley. January and mean annual temperatures have generally increased, both since 1940 and since 1970, and the warming trend extends beyond the lowest layers of the atmosphere. Snow depths showed high year-to-year variability, with trends tending to a slight decrease since 1970. Stuart's frost index model showed lower values over the past 17 years.

Properties and Distribution of Ground Ice
P.J. Kurfurst and S.R. Dallimore (TSDGSC)
Several types of massive ice, including buried glacial ice, have been found in the Tuktoyaktuk coastlands area. Their properties and behaviour differ due to different origin and type of host soil.

Mackenzie Delta Hydrology and Ecosystem
P. Marsh (NHRI)
Ongoing research illustrated the importance of permafrost in controlling the hydrological regime of delta lakes. It plays a major role in forming lake basins and affects water supply to the lake by: delaying and limiting snowmelt runoff due to the large negative soil heat-flux; and limiting ground-water flow from the lake. Without permafrost these lakes would experience a very different hydrological regime and would not maintain stable water-levels.

Permafrost Research - Norman Wells Pipeline
M.M. Burgess and A.S. Judge (TSDGSC) with K.L. McInnes (DIAND), C. Tarnocai (AC) and Interprovincial Pipeline
The project has developed an understanding of the behaviour of a small diameter, buried, "ambient temperature" oil pipeline in discontinuous permafrost. Instrumentation has shown that pipe temperatures are 70°C, and that mechanisms of pipe/ground heat exchange are complex, particularly beneath insulated thaw-sensitive slopes where thaw depths have begun to exceed predictions in several areas after only 6 years of operation. Monitoring of the right-of-way continues and contributes to global change research.

Thermal and Hydrological Investigations
C.R. Burn (GEOG/UBC)
Permafrost of the southern Yukon has degraded and cannot be sustained after a forest fire. Temperature profiles in permafrost at Mayo, Y.T. show warming in response to climatic trends of the last two decades.

Effects of Disturbances in the Subarctic
G.P. Kershaw, K.E. Evans, B.J. Gallinger and S. Nolte (GEOG/ALTA)
After six growing seasons, thaw depths continue to increase on cleared rights-of-way and in simulated pipeline trenches. The thaw depths beneath an experimental oil spill are increasing in response to higher surface temperatures and greater net radiation produced by lower albedo.

Palsa Evolution in Alpine Tundra
G.P. Kershaw, L.J. Kershaw and K. Skaret (GEOG/ALTA)
A project to determine the present status of permafrost features such as palsas and peat plateaux was initiated in July 1990. It will also consider the nature of seasonal changes in the active layer and microclimatic processes affecting it; describe the development of features and relate this to environmental change including climate; and construct a numerical/conceptual model of palsa evolution in the alpine, discontinuous permafrost environment. As yet data from the first field season have not been analyzed.

PERMAFROST - QUEBEC

Permafrost in Northern Quebec

M. Allard, M.-K. Seguin (CEN/LAVAL), B. Ladanyi (ENG/MONT), W. Pollard (GEOG/McG) et al.

New relationships have been established between the electrical and physical properties of permafrost, new information obtained on the thermal regime of permafrost in tidal marshes and along shorelines, thermal data acquired from >15 locations across northern Quebec, and radar data obtained on palsas, ice wedges and frost blisters.

PERMAFROST PROPERTIES

Failure of Frozen Sand under Triaxial Compression

B. Ladanyi and J.-F. Morel (NEC/EP)

When a dense granular material with a viscoplastic matrix, such as ice, is submitted to uniaxial or triaxial compression, one portion of its strength is thought to be due to the internal confinement resulting from tensile stresses generated in the matrix when it tends to oppose the dilation. A new conceptual model describing this phenomenon was checked by performing triaxial compression tests on frozen and unfrozen sand. The test results confirm that the effect of "internal confinement" or "dilatancy hardening" is responsible for about half the compression strength observed in uniaxial compression tests with ice-saturated frozen sand.

Borehole Dilatometer Creep and Relaxation Testing in Frozen Soils and Ice

B. Ladanyi, J.R. Murat, J. Sgaoula, M. Melouki and B. Touileb (NEC/EP)

The study comprised both *in-situ* tests, at two permafrost sites (CRREL Permafrost Tunnel, Alaska and Longyearbyen, Svalbard), and full-scale tests under well-controlled cold-room conditions. The results were interpreted by three methods (ageing-creep theory, reference-stress, and isochronous curves). The values of creep parameters determined from the borehole-dilatometer relaxation tests were found to agree well with those determined by some other testing methods, such as triaxial-compression and borehole-creep tests.

Modelling Coupled Processes in Freezing Soils

B. Ladanyi and M. Shen (NEC/EP)

The newly developed conceptual model and a numerical solution, involving a combination of the finite-difference method and the finite-element method, was successfully validated against laboratory test results published by Penner (1986), and against measurements made during a large-scale test on a buried chilled pipeline, which is being carried out in Caen, France. The method makes it possible to predict the stresses acting on a buried chilled pipeline under any given longitudinal pipeline-rigidity conditions.

Axial and Lateral Loads on Permafrost Piles

B. Ladanyi, A. Thériault and A. Foriero (NEC/EP)

Complete analytical and numerical solutions for stress redistribution with load and time in long, compressible, axially loaded piles embedded in permafrost have been obtained and compared with laboratory and field test results. For the latter, several different analytical and numerical solutions were developed and evaluated.

PERMAFROST - METHODS

Geophysics applied to permafrost

M.-K. Seguin, M. Allard, R. Lévesque, J. Stein, J.A. Pilon and F. Padilla (GEOL/LAVAL)

Electrical, seismic and electromagnetic (EM) [conventional and ground-probing radar] methods can define the lateral extent of the permafrost (PF) surface. Electrical and EM methods can also determine its vertical extent, but because of a hidden layer underneath the PF, the refraction seismic method is not effective. The temperature of PF was monitored with thermistors and ice and ice content detected using combined geophysical methods. The integration includes gravity, electrical resistivity, induced polarization, self potential, multifrequency-multiseparation EM techniques and ground-probing radar. Both surface and downhole geophysical methods are complementary for mapping PF distribution and obtaining information on its properties (e.g., density, electrical resistivity, chargeability, dielectric constant, dynamic elastic moduli, thermal conductivity, water and ice content).

Frozen Soil Processes

H.N. Hayhoe and D. Balchin (LRRC/AC)

Time-domain reflectometry and linear displacement transducers are useful for monitoring freezing and thawing processes under field conditions. Soil temperature gradients at the freezing front can be related to accumulative frost heave.

Electrical Freezing Potentials

V.R. Parameswaran (IAR/NRC) with J.R. Mackay (GEOG/UBC)

Ice negative potentials (50 to 80 mV) were measured on electrodes located at the freezing front in the core of a pingo. The advancing freezing front in successive years could be located by this technique.

GPR and EM Conductivity Surveys

R. Pelletier-Travis (Stennis Labs, NASA) and L. Davis (CANPOLAR)

GPR was able to measure peat thickness and delineate stratifications within the peat near Moosonee, Ontario. Airborne measurements work well up to about 5 m when it becomes difficult to detect the bottom of the peat. EM conductivity shows promise if the conductivity of the peat remains essentially constant.

Permafrost Distribution, History & Processes

A.S. Judge (TSDGSC)

Radar technologies were further explored as remote-sensing tools for permafrost and ground-ice mapping. The possible integration of SAR and GPR was evaluated with Atlantic Scientific and further applications of GPR examined in studies of fluvial processes with CAL. The deep subsurface thermal field in the Beaufort Sea region was mapped using industry borehole data. Results were tied to the distribution of permafrost and the recent glaciological history.

In-situ Creep Properties of Frozen Soils and Ice by Means of the Sharp Cone Test

B. Ladanyi, P. Talabard and J. Sgaoula (NEC/EP)

This method consists in pushing a smooth, low-angle cone into a predrilled conical portion of a borehole. The creep properties of the material are determined by applying a constant axial load to the cone, and by

observing its time-dependent axial displacement tending to enlarge the hole. The test results, obtained in ice and frozen sand under cold-room conditions, show that reasonably consistent values of creep parameters, comparable to some pertinent published data, can be obtained by this type of test.

B. Ladanyi, P. Huneault, B. Toulleb and A. Ducharme (NEC/EP) with Tom Lunne (Norway) and P. Vergobbi and B. Lhuiller (France)

Tests carried out in 1988 in frozen silt in the CRREL Permafrost Tunnel in Alaska, as well as those in sea ice on the east coast of Newfoundland (1990), have confirmed previous findings that, in a given frozen material, at a constant temperature, there is a unique relationship between the cone resistance and the cone penetration rate. This makes it possible to continuously profile frozen-soil strength down to a given depth, or to determine the frozen soil or ice strength vs. strain-rate behaviour within a selected soil layer.

Analysis of Ground Temperature Profiles

A.E. Taylor (TSDGSC)

A winch and logger system was used to measure quasi-continuous temperature profiles in boreholes and in the 1977 ice-core borehole on the Agassiz Ice Cap.

Heat & Mass Transfer in Frozen Porous Media

W.K.P. Van Loon (AUN)

Time-domain reflectometry is a very useful *in-situ* method for measuring liquid water content and bulk electrical conductivity in frozen soils.

PHYSICS OF ICE

Ice Properties

E. Whalley (SIMS/NRC)

The entropy of amorphous ice relative to that of ice Ic was determined by a new thermodynamic method. It is a small fraction of other estimates. The density of the translational and the rotational vibrations of high-density and low-density amorphous ice were determined by inelastic neutron scattering (with E.C. Svensson, V.F. Sears, J.H. Root and C. Szornel [AECL, Chalk R.] and E.D. Hallman [Laurentian Univ.]). The transverse and longitudinal translational vibrations and the rotational vibrations of ice are well separated. The harmonic component of the heat capacity was calculated from these spectra, and so the anharmonic component of the heat capacity was obtained for the first time for a polyatomic crystal. The Brillouin spectra of the crystalline phases of ice at 0-10 kbar and -35.5°C has been reported with H. Kiefte and M.J. Clouter (MUN).

FLOATING ICE - GENERAL

Physics of Ice

E.R. Pounder (PHYS/McG)

"The Physics of Ice", published by Pergamon in 1965, is being revised.

Borehole Indentor Measurements

N.K. Sinha (LTL/NRC)

In-situ tests were carried out on freshwater lake ice, first-year Labrador sea ice, freshwater ice-island shelf-ice and multiyear ice-island ice using the NRC borehole indentor system.

LAKE AND RIVER ICE - ARCTIC

Colour Lake, Axel Heiberg Island,

W.P. Adams, P.T. Doran, M.A. Ecclestone and J. Buttle (GEOG/TRENT)

Background information on Colour Lake, its catchment and the role of single and multi-year ice covers, has been collected and the results are being analyzed and prepared for publication.

Ice Regimes, Mackenzie Delta & Hay River

D.A. Sherstone (Science Inst. of the N.W.T., Box 1617, Yellowknife, N.W.T., X1A 2P2)

Ten-winters' monitoring rates of ice growth, the timing of maximum ice thickness and the rate of ice decay for the Mackenzie Delta confirm that maximum thickness is achieved later than earlier studies reported. Mackenzie Delta ice is consistently thinner in channels on the east side of the Delta, thicker on the west. Central channels show greater year-to-year variations. This may be due to freeze-up events and timing in Middle and Oniak Channels. Four winters' data from Hay River indicate maximum thickness is reached in the first two weeks of April for all sites. Ice can thin by as much as 50% prior to break-up.

Strength and Rupture of Decaying River-Ice

M.N. Demuth, T.D. Prowse and H.A.M. Chew (NHRI)

Based mainly on studies of Liard River ice, dominant failure modes contributing to ice-cover break-up have been identified and classified according to their scale, mechanism and rate of evolution. The role of large-scale flaws and ice-cover variability in the promotion of ice failure was examined. A physical model of ice-overthrust flexural failure was developed, describing an intact brash-ice fragmentation process.

The strength and variability of pre-break-up ice-covers was characterized with a borehole-jack indentor. A model, based on plasticity, describes the jack indentation characteristics and estimates ice-compressive strength. An ice-stiffness index, obtained using the jack, has allowed the determination of profile properties in structurally variable ice covers. This has important implications for the flexural properties used in ice-cover failure modelling.

Freshwater-Ice Break-Up Process

T.D. Prowse, M.N. Demuth and H.A.M. Chew (NHRI)

A relationship between changes in ice strength and internal melt porosity has been established from concurrent field measurements of energy balance and flexural strength. A preliminary model of the nature of the melt geometry has been developed and some quantification made of the effect of internal porosity changes on the optical properties of the cover.

The magnitude and relative importance of hydrothermal and atmospheric heat fluxes to the decay of an ice jam has been established. Results led to the first calculation of ice-jam porosity from field data.

Radiation-Ice Modelling

H.A.M. Chew, T.D. Prowse and M.N. Demuth (NHRI)

A solar radiation simulation system using a high-power arc lamp, from which the light is columnated and directed to a temperature and environment control chamber where incoming and transmitted energies were measured, has been set-up. Albedo and radiation measurements were made at Floral Pond and Waskesiu (Saskatchewan), and on the Liard River, near Fort

Simpson, N.W.T. HORZCODE, an AES model for calculating solar energy at the horizontal surface has been evaluated. Despite the lack of radiation data from Fort Simpson, some of the sub-models' predictions for energy at the horizontal surface agree well with the measured Liard River values.

Yukon River Headwaters Lakes

P.F. Hamblin, E.C. Carmack & J.C. Patterson (NWRI)
A thermodynamic model of an ice-covered lake was developed and tested on Lake Laberge (Y.T.): the water/lake-ice heat flux was quantified in terms of a sensible heat transfer coefficient; inflow mixing is controlled by outflow conditions in large ice-covered lakes.

LAKE AND RIVER ICE - E. CANADA

Ice in Lake Systems, Schefferville, P.Q.

W.P. Adams, M.A. Ecclestone & O. Choulik (GEOG/TRENT)
From 1977-1983, oxygen concentrations were monitored in seven lakes near Schefferville. Half did not thermally stratify during the summer. Winter oxygen depletion proceeded linearly from freeze-up in late-October until early-May, when the melting snowcover and increasing solar penetration through the ice cover resulted in an increase in photosynthesis and in the concentration of whole-lake oxygen. Winter depletion rates ranged from 0.047 g $O_2 \cdot m^{-2} \cdot d^{-1}$ in oligotrophic Lake Dian to 0.225 g $O_2 \cdot m^{-2} \cdot d^{-1}$ in Lake Lejeune. Rates appear to reflect the difference in trophic status rather than morphometric parameters.

Subice Layering Lac Laflamme, Quebec

J. Roberge (350 Latourelle #1, Québec, G1R 1C8)
The subice circulation of waters from five different origins was studied during spring melt. Three distinct low-pH episodes were recorded. The first (pH 5) occurred in the early melt period; snow and ice meltwaters layered beneath the ice forming a stratum ≈20 cm thick. The others, (pH 5.3 and 5.1) during the massive melt period, were due to peak flows of hillslope through-flow which entered the lake and formed a layer 20-40 cm thick in the water column. The ice cover thus not only modified the nearshore water quality by inducing thermal layering, but also strongly influenced the quality of the outflow waters due to the segregation and rapid evacuation of the through-flow and surface meltwaters.

Restigouche River Ice Study, N.B.

S. Beltaos (NWRI) and B.C. Burrell (NBEPS)
The configuration of a jam near the toe on the Restigouche River has been predicted using a numerical algorithm that solves appropriate differential equations.

GPR Ice Jam Surveys, Saint John River, N.B.

S. Ismail (N.B. Power) and Les Davis (CANPOLAR)
A ground-penetrating radar, operating at 50 MHz, could detect and estimate the thickness of both broken ice and slush ice to depths of seven metres on the Saint John River near Perth-Andover, New Brunswick.

Nashwaak River, N.B.

N. El-Jabi (ENG/MONCTON)
A non-dimensional index, based on hydro-meterological parameters, has been developed for forecasting ice jamming and break-up for the Nashwaak River, N.B.

Ice-Jam Occurrence and Break-Up

S. Beltaos and J. Wong (NWRI)
A semi-empirical method has been developed to forecast the onset of river-ice break-up, based on analysis of fracture processes and historical data. A numerical model (RIVJAM) can compute the longitudinal variation of thickness and water-levels along a break-up jam, including the toe region.
S. Sarraf (ENG/CONC)
The transient behaviour of river flow during ice-jam formation and release has been investigated. This has included testing and validating numerical models, particularly a 2-D model based on depth-averaged hydro- and thermodynamic equations, and investigating the heat-flux and melting-rate of a fragmented ice-cover. Heat exchanges with the atmosphere have been computed for varying meteorological conditions.

Geological aspects of drift ice

J.-C. Dionne (CEN & GEOG/LAVAL)
In studying ice as an agent of erosion, transportation and sedimentation, in various environments, drift ice has been found to be a major agent for transporting coarse and fine-grained sediment in the St. Lawrence estuary.

Model Ice Material

S. Beltaos and J. Wong (NWRI)
SYG-ICE is a material based on plaster, PVC resin and glass microbubbles. It has the required mechanical properties to simulate ice breaking under laboratory conditions and attendant scale reductions.

SEA ICE - ARCTIC

Long-term variability in the Arctic Ocean

E.C. Carmack (IOS)
Recent studies show that exports of freshwater, from river inflow and sea-ice formation, may control the thermohaline circulation of the world ocean, and thus have a major effect on global climate.
D.M. Holland (MET/McG)
Working is starting on comparing coupled ice/ocean general circulation model results with observations of ice characteristics to understand the causes of interannual variability.

Arctic Buoy Program

W.D. Hume (4999-98th Ave, Edmonton, Alta, T6B 2X3)
AES deployed two buoys in the Arctic Ocean in 1990, when other international participants deployed in excess of 20 buoys. Data are transmitted over the Global Telecommunications System and archived in Ottawa.

Sea Ice Diatoms

M. Poulin and P.B. Hamilton (PS)
Work is underway on the taxonomic, morphological and phytogeographical characteristics of about 100 diatom species inhabiting the lower sections of sea ice in the Canadian Arctic.

Inuit Use of Sea Ice

R. Riewe (ZOO/MAN)
Most present-day Inuit communities lie along the arctic coastline and rely on marine ecosystems. Hunting territories in the Nunavut region vary from 42,600 to 205,000 km² with an average of 107,337 km²; about one-third of these encompass marine areas. The Inuit have an extensive language and technology for sea ice.

Their ecological knowledge of this environment is extremely rich but has received little attention from southern biologists.

Climate Change and Beaufort Sea Ice

T. Agnew (CCC/AES)

A 50% or more reduction in sea ice thickness in winter is one of the estimated potential changes in the Beaufort Sea ice regime due to a doubling of CO_2 concentrations.

Beaufort Sea Ice Forecast Model Verification

T.G. Brown, F.G. Bercha, B. Dixit and R.W. Marcellus (BERCHA)

Statistical procedures were developed for verification of ice movement, total and partial ice concentrations, ice pressure, and ice-edge location in which the output from any sea-ice forecast model is compared with Beaufort Sea data acquired from two periods in 1986. The data include the necessary information to execute the sea-ice forecast model, including initial ice conditions, ocean-currents, and wind fields for a total duration of 120 hours in each period. The output verification data include all necessary information to cover the majority of the current regional ice-modelled area which is approximately 800 km².

Pack Ice Driving Forces

R.M.W. Frederking and M. Sayed (LTL/NRC)

Pack-ice driving forces were measured during March to May 1991 in the Beaufort Sea. Also, stress measurements were made in the marginal ice zone of the Barents Sea with the Norwegian Hydrotechnical Laboratory and C-CORE.

Ice Subsurface Characterization

H. Melling (IOS)

Sonar deployments in the Beaufort Sea in 1990 showed their suitability for ice-field measurements. The average thickness of ice was roughly twice that attributable to local thermodynamic growth. The most extreme feature observed had a draft of 27 m.

Ridge Statistics

M. Sayed and R.M.W. Frederking (LTL/NRC)

An aerial survey of the Beaufort Sea ice cover was made in April 1991. It was co-ordinated with measurements of keel geometry by IOS and BIO. Analysis of the two-dimensional ridging characteristics in the Beaufort Sea is underway in collaboration with J. Lewis (GEOG/McG).

Energy-Flux Density Estimation, North Water

K. Steffen (CIRES)

Based on satellite passive-microwave measurements, more than 20% young ice (<0.3 m) was found in the North Water area (100,000 km²) throughout most winters, with maximal values of 60% and more, and only a few percent of open water. The mean loss for the entire North Water was found to be 77 $W \cdot m^{-2}$ for November to March 1986-87. Future work will involve monitoring the North Water area with ERS-1 SAR data during the two winters 1992 and 1993.

SEA ICE - EAST COAST

Sea Ice and Atmospheric Circulation

T. Agnew (CCC/AES)

For the Baffin Bay/Davis Strait areas both advection of ice and *in-situ* freezing play important roles in ice formation. In the Greenland Sea, extremes of sea-ice cover are determined more by atmospheric advection.

Northumberland Strait - Ice Studies

T.G. Brown, J.R. Bruce and A.W. Poon (BERCHA)

Simulation models show the impact of a bridge on the ice regime in Northumberland Strait in terms of blocking ice moving through the Strait and its effect on the length of the ice season. The models show that maximum delays of as little as 1 to 2 days will occur. Supporting studies characterized ice in the Strait in terms of floe sizes, ridging frequencies, strengths, and thicknesses. Techniques used included high-resolution synthetic-aperture radar data, field programs of ridge measurement and ice sampling, and analysis of photos.

Sea Ice off Labrador

M. Ikeda (BIO)

Labrador ice forms mainly north of 55°N and is advected southward. Ice cover shows clear inter-annual variabilities, which are mostly accounted for by air temperature. Convection and shoreward heat advection limit offshore ice extension. Remote-sensing data are useful for ice-motion detection and ocean current estimates.

C.L. Tang (BIO)

The seasonal advance and retreat of the sea ice over the Newfoundland Shelf is controlled by advection and heat balance at the air/ice and ice/water interfaces. The short-term ice movement is primarily wind-driven being linearly related to the surface wind velocity.

Floe Collisions in the Labrador Ice Margin

G.B. Crocker and R. McKenna (C-CORE)

Floe collisions account for only a small percentage of wave energy decay in marginal ice zones (approx. 10% or less). They do however play an important role in determining the floe size distributions and the deterioration of floes near the ice edge.

SEA ICE - ICEBERGS

East Coast Ice and Climate Change

R.D. Brown (CCC/AES)

The advection of upstream ice from Baffin Bay/Davis Strait onto the Labrador Shelf in spring, and local spring wind conditions, were found to be key factors associated with inter-annual variability in iceberg severity on the Grand Banks. Upstream processes, such as iceberg calving, were not as important over the last ~100-year time-scale considered.

Iceberg Movement in Sea Ice

S. Venkatesh (CCC/AES)

Iceberg drift in sea ice that is not under stress is not significantly affected by the presence of the sea ice. The deterioration of an iceberg as it emerges from sea ice is very well simulated by the deterioration model.

Ice and Iceberg Forecast System (IIFS)

M. El-Tahan (CORETEC)

An integrated sea-ice and iceberg forecast and data-management system has been developed. It includes operationally tested iceberg and sea-ice-edge drift-prediction models as well as a comprehensive data base on icebergs (size parameters, drift trajectories, drift speed, densities, flux) measured wind and current data and ice-edge movements.

Habbakuk Project

L.W. Gold (LTL/NRC)

A record of Canadian participation in the Habbakuk Project during World War II, and of the reports arising from that work, has been prepared and is ready for publication. The proposal called for construction of a giant "iceberg" aircraft carrier out of "pykrete" (an ice and frozen wood pulp mixture).

SEA ICE - REMOTE SENSING

SAR Ice Interpretation Guide

F.G. Bercha, V.L. Shaw, J.W. Steen and J.A. Dechka (BERCHA)

The sea-ice interpretation guide, developed for the AES sea-ice observers, presents the principles of radar, interpretation of radar imagery, and numerous examples of sea-ice interpretation.

Sensing of Sea Ice

J. Sutton and S. Patterson (INTERA Kenting, 2 Gurdwara Rd, Suite 200, Nepean, Ont, K2E 1A2)

SAR and SLAR is used to monitor ice conditions through the data analysis and collection capabilities of STAR-1 and STAR-2, complemented by laser/IR/air-photo data. Results are mostly in confidential reports to clients (i.e., oil companies, shipping companies, etc.)

E.M. Krakowski (INTERA Technologies Ltd., 2500 - 101 6th Ave S.W., Calgary, Alta, T2P 3P4)

SAR imagery of ice conditions in Canadian waters is being collected for the Canadian Coast Guard.

Marine Currents Determined from Ice Flow

J.-M.M. Dubois et P. Larouche (CARTEL)

The direction and speed of marine currents is being evaluated by remote sensing of the displacement of ice blocks. Wind stress and the Coriolis effect must be considered. With MSS images, both analogue and digital techniques provide comparable results.

Acoustic Remote Sensing of Sea Ice

Y. Xie and D.M. Farmer (IOS)

Snow a few centimetres thick almost eliminates the thermal response of sea ice to cooling effects at night. The sound signatures from cracking, e.g., the duration and the spectra of the signal, can be used to infer elastic parameters of an ice cover and its thickness. Ice break-ups, especially of land-fast ice, leads to ice rubbing between floes, which induces a pure tone sound in the ocean. Its frequency is related to the shear wave speed and thickness of the ice sheet.

Ice Radar for Measuring Thickness of Ice

K. Iizuka (ENG/UT)

A surface-borne ice radar has been successful developed and tested. It is now being converted into an airborne radar for measuring ice thickness.

Ice Thickness from Ground Penetrating Radar

J.P. Todoeschuk (now with ICI Explosives Technical Centre, 801 Richelieu Blvd, McMasterville, P.Q., J3G 1T9) and R.I. Verrall (DREP)

Ground-penetrating radar (GPR) gives good thickness results on multi-year sea ice and on permanent land-fast ice; that of Ellesmere Island often has parallel ridges and troughs on the surface called rolls. Elevation and GPR thickness measurements near Stuckberry Point show rolls on the bottom of the ice that have the same wavelength, larger amplitude, and a 90° phase shift.

GPR for Long-Range Ocean Remote Sensing

A.M. Ponsford, L.D. Cuff and S.K. Srivastava (NORDCO Ltd., Donovan's Industrial Park, 34 Glencoe Dr, Box 8833, St. John's, Nfld, A1B 3T2)

Long-range detection and tracking of icebergs, vessels and aircraft, up to 500 km, has been achieved using computer simulation software and an operational radar, as well as mapping of the sea-ice/open-sea boundaries. There is excellent agreement between computer simulation and measured data. Models were also developed for the radar cross section of icebergs and propagation loss over sea ice.

Surface-Based Radar for Ice Surveillance

S. Haykin, B. Currie, C. Krasnor, V. Kezys and P. Weber (CRL/McM)

A field experiment was conducted in June 1989 at Cape Bonavista, Newfoundland, using CRL's experimental IPIX radar. This X-band system permits the study of numerous radar parameters including resolution, pulse compression, coherence, Doppler processing, dual-polarization, and within-band dual-frequency operation. The radar is computer-controlled and data are collected digitally. The Doppler and polarization characteristics of the ice targets differ substantially from the sea, permitting significantly improved detection. Collaboration is with Litton Systems Canada, who will commercialize the final radar design.

Sea-Ice and Snow Thickness Sensor

J.R. Rossiter, L. Lalumiere (CANPOLAR) and S. Holladay (Aerodat Ltd.)

Initial measurements of sea-ice thickness in the Arctic and off Canada's East Coast, based on EM induction, have been successful. A pre-production prototype incorporating a radar-based snow-thickness sensor is being tested in the Beaufort Sea in April 1991.

Acoustic Measurements of Ice Properties

G.B. Crocker, J. Guigné and P. Hunt (C-CORE)

Preliminary assessments of using non-linear acoustic techniques to measure ice thickness, underside roughness, internal structure, etc. are very encouraging. The ice/water and ice/air interfaces could be resolved with millimetre-scale accuracy. Also, bubble layers in the ice clearly showed up as distinct acoustic returns.

Laser Profiling of Antarctic Ice

H.B. Granberg (CARTEL) with M. Leppäranta (Finnish Institute for Marine Research)

Preliminary results of an evaluation of ice ridging characteristics show a greater amount of ice ridging in the Weddell Sea than in the Ross Sea.

Laser Profiling for ERS-1 (BEPERS-88)

H.B. Granberg (CARTEL) with J.E. Lewis (McG) and M. Leppäranta (Finnish Institute for Marine Res.)

Some 60 laser profiles, 6 to 24-km long, were obtained in the Bay of Bothnia to characterize ice surface roughness for calibrating and interpreting SAR images.

SAR/Laser Profile Analysis

H.B. Granberg (CARTEL) with T. Thompson, B. Hakansson and M. Moberg (Swedish Meteorological and Hydrological Institute)

A study is underway to examine the efficiency of SAR as an indicator of ice conditions (as determined by aerial photography and laser/video profiles).

SPRAY ICE AND ICING

Deformation properties of spray ice
L. Domaschuk and D.H. Shields (ENG/MAN)
There are still insufficient data to determine the consolidation properties of spray ice under varying conditions of initial density, pressure and porewater salinity.

Sea-Ice Islands from Ice-Water Mixtures
K. Szilder, E.P. Lozowski & T.W. Forest (MET/ALTA)
Ice-water mixtures for ice-island construction are highly efficient and not very sensitive to air temperature and wind. The advantage over spraying and flooding is particularly apparent for warm weather conditions.

Extension of Spray Ice Technology
J.S. Weaver, J.P. Poplin and K.R. Croasdale (ESSO)
Methods were evaluated to reduce spray-ice ablation and edge erosion, including surface coatings of gravel and wood products and fabric sheets. The drilling season on spray-ice islands can probably be extended into June. Ice forces were measured in the landfast ice around the Molikpaq at the Isserk I-15 drilling location. Ways of reducing the loads that an ice sheet can exert on a structure were assessed. The newest program is investigating the sliding resistance of grounded ice-rubble with a spray-ice surcharge. The use of snow as an ice-load mitigation agent, and a small helicopter-transportable spray system are also being evaluated.

Sensor for Detection of Atmospheric Ice
S. Inkpen, C. Nolan (INSTRUMAR Ltd, Box 13246, Stn A, St. John's, Nfld, A1B 4A5) with M. Oleskiew (NRC)
A sensor which detects ice accretion on ground-based structures (IM101 Ice Monitor) uses surface electrical impedance and surface temperature. It can reliably measure atmospheric icing events. Detection levels can be adjusted to reflect the sensitivity required for differing applications. The unit will be available commercially in July 1991. Work continues on a more advanced version for aircraft ice sensing.

Modelling of Ice Growth
E.P. Lozowski, K. Szilder and W.P. Zakrzewski (MET/ALTA)
Icing is a complex phenomenon that depends on: the mechanism and rate of water delivery to the target; heat transfer; and synoptic conditions. For ship icing, icing rates and ice loads are ship-dependent and vary over the ship. Icing is most sensitive to air temperature, wind speed, sea surface temperature, and ship speed and heading. It can significantly reduce ship stability and cause a ship to capsize.

SEA ICE PROPERTIES

Fractal Characteristics of Sea Ice
G.B. Crocker and G. Cammaert (C-CORE)
Uni-axial crushing of sea-ice and lake-ice samples produced classic fractal particle-size distribution and distinctive fractal dimensions.

Brittle-Ductile Transition during Indentation
L.W. Gold (LTL/NRC)
The maximum in the dependence of the failure stress on indentation rate for a rectangular rigid indenter acting on the edge of a large ice plate can be explained using elastic theory and a strain-rate dependent fracture toughness. For the criteria of failure applied, the indentation pressure at failure varied inversely as the square root of the width of the indenter. Work is continuing on other shapes of indenters.

Creep of Mono- and Bi- Ice Crystals
B. Michel and B. Doyon (LMG/LAVAL)
For monocrystals, the creep law depends essentially on the reduced shear stress on the basal plane, except for large crystals where kinking occurs. The creep for two crystals introduces strain hardening and a much reduced rate of permanent creep in the worst-oriented crystal.

Crack Formation in Columnar-Grained Ice
L.W. Gold and S.J. Jones (IMD)
The ratio of transgranular to grain boundary cracks decreases with increasing strain rate and decreasing grain size and temperature. Both families have a log-normal distribution in crack width. The mean value of the crack width depends on strain, strain rate, temperature, and grain size. The strain rate and temperature dependence found for the elastic modulus agree with published results.

Deformation and Current Effects on Fabric Development in Columnar Ice
B. Michel, E. Stander and P. Barrette (LMG/LAVAL)
Large deformations lead to important recrystallization and a 3-point preferred orientation caused by slip plane rotation and dynamic recrystallization.

Fracture of Ice
B. Parsons (IMD)
Field work in Resolute Bay in 1991 was to determine the effects, if any, of ageing and blunting of cracks on the fracture toughness and strength of ice.

Constitutive Modelling of Ice
N.K. Sinha (LTL/NRC)
The Sinha constitutive model was extended to incorporate the effects of porosity and grain structure.

Model Ice Development
D. Spencer and S.J. Jones (IMD)
An underwater carriage has been designed and built, from which small air bubbles (~1 mm diameter) are released. These bubbles get incorporated into the growing ice sheet, thus reducing its density to a realistic full-scale value for sea ice of approx. 0.9 Mg/m^3.

Behaviour of Oil Spills in Ice-Infested Waters
S. Venkatesh (CCC/AES)
The following results have been obtained: for ice concentrations >30%, the oil drifts with the ice; equilibrium oil thickness in slush-ice is nearly four times that on cold water; at an ice concentration of ~80%, the oil on the water surface gets trapped between ice floes and does not spread laterally.

SEA ICE - IMPACTS ON STRUCTURES

Sloping Structure Research
K.R. Croasdale and M. Metge (ESSO)
Tests were performed on a 1/10th-scale model of a six-sided conical-shaped cone with facets in 1988/89, and a 1/20th-scale model similar to that used earlier in 1989/90. The changes in scale made it possible to model larger prototype ridges with dimensions closer to design values. Two seasons of large-scale tests in the

ESSO Ice Basin in Calgary have been successfully completed. The ice properties in year 2 exceeded expectations partly due to the installation of a new spray-ice system for making weaker ice. Four series of tests were carried out in the first year and 5 in the second year. Each series consisted of at least two runs of ridges and sheet ice.

Ice Interaction with Structures

I.J. Jordaan et al. (Ocean Eng. Res. Cen./ENG/MUN)

It has been found that viscoelasticity, fracture and damage mechanics are the appropriate tools for modelling the fracture and crushing of ice during interaction with structures.

Ice Crushing by Low Velocity Impact and Cratering Mechanisms

H.H. Schloessin (GPHYS/WEST) with G.W. Timco and R.M.W. Frederking (LTL/NRC)

The characteristic time sequences of elastic and plastic impact phases were determined from accelerometer pressure-gauge and load-cell records of three sets of 200-600 $cm \cdot s^{-1}$ impact tests, carried out at the Hydraulics Laboratory (IME/NRC) on mostly S-2 ice. The impacts, of ~7 ms total duration, consist of a rapid deceleration (braking) phase followed by a main, plastic, slow deceleration phase with build-up to maximum contact pressure and subsequent recovery, for ice 20.3 to 25.4-cm thick, and of a rapid deceleration followed by a slow deceleration phase, already continuing onsets of recovery, for ice 30.5 to 36.8-cm thick. The observations emphasize that plastic deformation and fracture of ice sheets consisting of large grains with preferred orientation reflect the prevalent single-crystal anisotropy.

Bearing Capacity of Ice

N.K. Sinha (LTL/NRC)

A finite-element numerical analysis has been made to predict the response of a floating drilling platform using a realistic rheological model for ice developed at NRC. A revised manual will be produced for aircraft operations on sea-ice covers for National Defence. During Winterlude in Ottawa, measurements were made of the crowd-induced deflection of ice on Dows Lake.

Computer Simulation of Ice Dynamics

O.G. Vinogradov, A.M. Vinogradov, A. Springer and P. Wierzba (ENG/CAL)

The methodology and computer code for simulating the motion of broken ice against obstructions are developed. The dynamic ice-structure interaction in the buckling mode of failure was investigated using a Monte Carlo simulation.

Behaviour of Broken Ice Rubble

M. Sayed and G.W. Timco (LTL/NRC)

Measurements of the behaviour and flow of crushed ice were made in small-scale laboratory tests, particularly the pressures associated with the extrusion of crushed ice particles. Laboratory tests were also performed to measure the bulk behaviour of ice rubble using a newly developed, large (1 m x 1 m x 0.5 m) bi-axial compression test cell. A field project on the sliding resistance of spray-ice surcharged rubble on soft clay was conducted as Joint Industry Project with ESSO.

Behaviour of Ice Rubble

T.T. Wong (Hardy BBT Ltd., 219-18 Str. SE, Calgary, Alta, T2E 6J5) and N.R. Morgenstern (ENG/ALTA)

Ice rubble belongs to the class of particulate materials made up of deformable (or weak) grains. An elasto-plastic constitutive model was developed for young broken ice. Berm geometry and rubble accumulation will affect ice-load transmission.

Field Measurements of Ice Forces

R.M.W. Frederking and M. Sayed (LTL/NRC)

Medium-scale indentation tests were performed at the Ice Island Research Station. Ice-force measurements were continued on three light piers in the St. Lawrence Seaway. Local impact forces on bridge piers were measured on an instrumented pier in the Rideau River.

Ship Interactions with Actual Ice Conditions

C. Daley (FLEET)

A simple ice-edge brittle-failure model has been developed which is capable of reproducing many of the features of tests of ice-block, and ice-face crushing tests, including - force time-histories, ice-flake size distribution, width of high-pressure solid ice contact, ice-force statistical properties. There has been some progress in ice-cover description, and methods to handle general ship interactions with non-infinite ice using fractal geometries.

Ice Forces on Ships and Structures

F.M. Williams (IMD)

Full-scale trials of the *CCGS Sir John Franklin* were conducted in 1991 off the coast of Newfoundland. Considerable data on the properties of the ice being traversed were obtained. Model scale experiments were conducted on a conical structure in the IMD ice tank.

Ice/Propeller Interaction

S. Newbury and S.J. Jones (IMD)

A new project will determine the relevant ice/propeller interaction forces for revised Arctic Machinery Regulations being developed by the Canadian Coast Guard. It is a joint collaboration with the Finnish Board of Navigation that will run for three years.

Structural Response Due to Ice Loading

G.W. Timco (LTL/NRC)

Tests were performed on ice loads due to dynamic ice loading. Models of the Great Belt Link (Denmark) and the JZ20 platform (Bohai Bay, China) were tested to measure the dynamic amplifications of loads due to structural vibrations.

Impact Tests on Freshwater Ice

G.W. Timco and R.M.W. Frederking (LTL/NRC)

Laboratory tests were conducted on the forces and pressures associated with low-speed (2-6 $m \cdot s^{-1}$) impact of projectiles on sheets of freshwater ice. Various conditions of impact energy, projectile geometry and ice geometry were used. The results provide insight into ice behaviour and pressures during impact loading.

Abbreviations used

AC = Agriculture Canada, Ottawa, Ontario, K1A 0C6
ACC = Alpine Club of Canada, Canmore, Alta, T0L 0C0
AES = Atmospheric Environment Service, 4905 Dufferin Street, Downsview, Ont, M3H 5T4

AESR = Scientific Services, AES, Box 480, Regina, Sask, S4P 3Y4
ALTA = Univ. of Alta, Edmonton, Alta, T6G 2H4
AUN = Agricultural Univ., Duivendal 1, 6701 P Wageningen, The Netherlands
BCIT = Survey Dept, BC Inst. of Technology, 3700 Willingdon, Burnaby, BC, V5G 3H2
BERCHA = F.G. Bercha and Assoc. (Alta) Ltd., 250 - 1220 Kensington Rd NW, Calgary, Alta, T2N 3P5
BIO = Bedford Inst. of Oceanography, Box 1006, Dartmouth, N.S., B2Y 4A2
CAL = Univ. Calgary, Calgary, Alta, T2N 1N4
CANPOLAR = CANPOLAR Consultants Ltd., Unit 4, 265 Rimrock Rd, Toronto, Ont, M3J 3C6
CARL = Carleton Univ., Ottawa, Ont, K1S 5B6
CARTEL = Centre d'applications et de recherches en télédétection, Univ. de Sherbrooke, 2500 blvd Univ., Sherbrooke (PQ), J1K 2R1
CCC = Canadian Climate Centre, AES
C-CORE = Centre for Cold Ocean Resources Engineering, MUN
CCRS = Canada Centre for Remote Sensing, 1547 Merivale Rd, Ottawa, Ont, K1A 0Y7
CEN = Centre d'Études nordiques, LAVAL
CIRES = Coop. Inst. for Res. in Environmental Sci., Univ. of Colorado, Boulder, CO 80309-0216, U.S.A.
CONC = Univ. Concordia, Montréal (PQ), H3G 1M8
CORETEC = CORETEC Inc., Cold Regions Research & Technology, Box 2638, St. John's, Nfld, A1C 6K1
CRL = Communications Research Lab., ENG/McM
CRRC = Cold Regions Research Centre, WLU
CSWI = Canadian Snow and Wind Inst., Unit 1, 335 Laird Road, Guelph, Ont, N1H 6J3
DIAND = Dept. of Indian and Northern Affairs
DREP = Defence Res. Est. Pacific, FMO, Victoria, B.C., V0S 1B0
DRES = Defence Res. Est. Suffield, Alta
DREV = Defence Res. Est. Valcartier, Box 8800, Courcelette (PQ), G0A 1R0
EC = Environment Canada
EMR = Energy, Mines & Res. Canada, Ottawa, Ont.
EP = École Polytechnique, CP 6079, Succ. A, Montréal (PQ), H3C 3A7
ESSO = Esso Resources Canada Ltd., 3535 Research Rd N.W., Calgary, Alta, T2S 2K8
FOC = Fisheries and Oceans Canada
FLEET = Fleet Technology Ltd, 311 Legget Dr., Kanata, Ont, K2K 1Z8
GCS = Glacier Consulting Services, 2225 Prince of Wales Drive, Ottawa, Ont, K2E 6Z8
GDGSC = GPHYS/GSC, 1 Observ. Cres, K1A 0Y3
GRC = Geotechnical Res. Centre, McG, 817 Sherbrooke Str. W., H3A 2K6
GSC = Geological Survey of Canada, Ottawa, Ont.
GUELPH = Univ. of Guelph, Guelph, Ont, N1G 2W1
IAR = Institute for Aerospace Research, NRC
IMD = Inst. of Marine Dynamics, NRC, Box 12093, Station A, St. John's, Nfld, A1B 3T5
INRS = Inst. national de la recherche scientifique, 2700 Einstein, CP 7500, Ste-Foy (Québec), G1V 4C7
IOS = Inst. of Ocean Sciences, Box 6000, 9860 West Saanich Rd, Sidney, B.C., V8L 4B2
LAVAL = Univ. Laval, Cité universitaire, Ste-Foy (PQ), G1K 7P4
LMG = Lab. de mécanique de glace, ENG/LAVAL
LRRC = Land Resource Res. Centre, Res. Branch, AC
LRS = Dept Land Resource Sci., Ont Agricultural Coll., GUELPH
LTL = Low Temperature Lab, Div. Mechanical Engineering, NRC
MAN = Univ. of Manitoba, Winnipeg, Man, R3T 2N2
McG = McGill Univ., Montréal, (PQ) H3A 2K6
McM = McMaster Univ., Hamilton, Ont, L8S 4K1
MONCTON = Univ. de Moncton, Moncton (N-B), E1A 3E9
MUN = Memorial Univ. of Nfld, St. John's, Nfld, A1B 3X9
NBEPS = Environmental Planning and Science Br., Dept of the Environment, Fredericton, N.B.
NEC = Northern Engineering Centre, EP
NHRI = Nat. Hydrology Res. Inst., EC, 11 Innovation Blvd, Saskatoon, Sask, S7N 3H5
NRC = National Res. Council, Ottawa, Ont, K1A 0R6
NWRI = Nat. Water Res. Inst., EC, 867 Lakeshore Rd, Box 5050, Burlington, Ont, L7R 4A6
OTT = Univ. of Ottawa, Ottawa, Ont, K1N 6N5
PS = Phycology Sect., Botany Div., Cdn Museum of Nature, Box 3443, Station 'D', Ottawa, Ont, K1P 6P4
RICK = Karl E. Ricker, 868 11th Str., West Vancouver, BC, V7T 2M2
SASK = Univ. of Sask, Saskatoon, Sask, S7N 0W0
SCRS = Swift Current Research Stn, AC, Box 1030, Swift Current, Sask, S9H 3X2
SIMS = Steacie Inst. for Molecular Science, NRC
SNOW = Snowline Research and Consulting Ltd., #2304, 8805 Hudson Str., Vancouver, BC, V6P 4M9
TOR = Univ. of Toronto, Toronto, Ont, M5S 1A4
TRENT = Trent Univ., Box 4800, Peterborough, Ont, K9J 7B8
TSDGSC = Terrain Sciences Div. (GSC), 601 Booth Str., K1A 0E8
UBC = Univ. of B.C., Vancouver, BC, V6T 1Z4
UQAC = Dept des Sciences Appliquées, Univ. du Québec à Chicoutimi, Chicoutimi (PQ), G7H 2B1
UTE = Erindale Coll., UT, 100 St. George Street, Mississauga, Ont, M5S 1A1
WATER = Univ. of Waterloo, Waterloo, Ont, N2L 3G1
WEST = Univ. of Western Ontario, London, Ont, N6A 5B7
WIND = Univ. of Windsor, Windsor, Ont, N9B 3P4
WLU = Wilfrid Laurier Univ., Waterloo, Ont, N2L 3C5
YORKA = Atkinson Coll., York Univ., Ont, M3J 1P3

ENG = Engineering
ES = Earth Sciences
FOR = Forestry
GA = Geophysics & Astronomy
GEOG = Geography
GPHYS = Geophysics
MET = Meteorology
PHYS = Physics
ZOO = Zoology

C. Simon L. Ommanney